REPORT DOCUMENTATION PAGE

AFRL-SR-AR-TR-02-

0352

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE

3. REPORT TYPE AND DATES COVERED

12/1/00 to 11/30/01 Final

4. TITLE AND SUBTITLE

Ultrafast Optical Wavelength Shuffling based on Nonlinear Pho;tonics Crystals

5. FUNDING NUMBERS

61102F

2305/DX

6. AUTHOR(S)

Professor McCaughan

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Univ of Wisconsin
750 University Avenue
Madison WI 53706-1490

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

Department of the Air Force
Air Force Office of Sdentific Research
801 N. Randolph St Rm 732
Arlington. VA 22203-1977

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

F49620-01-1-0077

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION AVAILABILITY STATEMENT

Distribution Statement A. Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

At the time of this proposal we had developed the theoretical foundation for analyzing 2D periodic second order nonlinearities, from which we developed demonstration of simultaneous optical wavelength interchange [I]. shown that a properly designed 2-D quadratic nonlinear lattice can be used to produce a simultaneous, one-step, interchange of data between two carrier wavelengths X[Pj˜)˜˜ (Fig. 1). The two DFG processes essentially "diffract" ˜ the Interconverted signals from the unconverted ones, providing spatial segregation to eliminate coherent in band cross talk. Subsequent to this, we presented the first experimental demonstration of simultaneous optical wavelength interchange [2,3]. The nonlinear lattice, fabricated in L1NbO3, was designed to interchange the wavelengths 1535 nm and 1555 nm a theoretical was In that paper, Figure 1. Schematic representation of simultaneous wavelength interchange in 2D periodicall poled LiNbO2.

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14. SUBJECT TERMS

15. NUMBER OF PAGES

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	UL

GP

144-JZ04
F49620-01-1-0071
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ULTRAFAST OPTICAL WAVELENGTH SHUFFLING BASED ON NONLINEAR PHOTONIC CRYSTALS
FINAL REPORT

Agency: DOD, Air Force, Arlington VA
Project Director: Leon McCaughan
Contract period: 12/01/00 through 11/30/01

At the time of this proposal we had developed the theoretical foundation for analyzing 2D periodic second order nonlinearities, from which we developed a theoretical demonstration of simultaneous optical wavelength interchange [1]. In that paper, it was shown that a properly designed 2-D quadratic nonlinear lattice can be used to produce a simultaneous, one-step, interchange of data between two carrier wavelengths (Fig. 1). The two DFG processes essentially "diffract" the interconverted signals from the unconverted ones, providing spatial segregation to eliminate coherent in band cross talk. Subsequent to this, we presented the first experimental demonstration of simultaneous optical wavelength interchange [2,3]. The nonlinear lattice, fabricated in $LiNbO_3$, was designed to interchange the wavelengths 1535 nm and 1555 nm (Fig. 2).

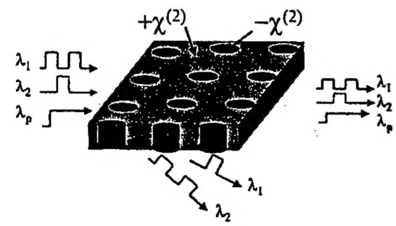

Figure 1. Schematic representation of simultaneous wavelength interchange in 2D periodically poled $LiNbO_3$.

The large refractive index of $LiNbO_3$ (n~ 2.2) also makes it an attractive material in which to produce a new engineered material: 2D nonlinear photonic crystals (NLPCs) – in which both the refractive index and the nonlinearity is periodically patterned. The periodic index distribution can serve as an optical bandgap material; defect waveguides fabricated in this material will be highly confining. This confinement will greatly enhance optical nonlinear processes such as wavelength translation.

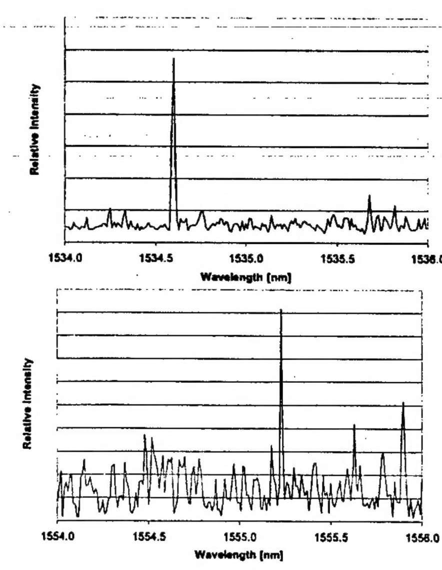

Fig. 2. Output spectra from 2D nonlinear lattice in LiNbO3.

The high chemical stability of crystalline $LiNbO_3$, however, effectively precludes the use of standard photolithographic patterning techniques. We have developed a two-stage growth method for fabricating patterned crystalline $LiNbO_3$ structures for PC and other photonic applications [4,5]. The method uses atmospheric chemical vapor deposition (CVD) to produce an amorphous $LiNbO_3$ film. We have begun to pattern these films using conventional photo-lithography and chemical and dry

etching techniques. (Alternatively, a standard lift-off process, using SiO_2 as a masking material, can be used to produce a desired pattern.) The crystalline LiNbO3 substrate serves as an etch stop. When grown on $LiNbO_3$ substrates, a post-growth anneal converts the amorphous film to single crystal $LiNbO_3$. Figure 3a is a cross-sectional TEM image of an amorphous $LiNbO_3$ film after annealing for 1 hour at 1100°C. The inset is the corresponding $[01\bar{1}0]$ zone axis selected area diffraction pattern taken from the film/substrate interface area in the image, demonstrating the single crystal epitaxial nature of the layer. The inclined lines are bend contours; the horizontal band is a thickness fringe. Figure 3b is a scanning electron micrograph of a photolithographically patterned, etched ($HF:H_2O$), and annealed (1000°C) $LiNbO_3$ film.

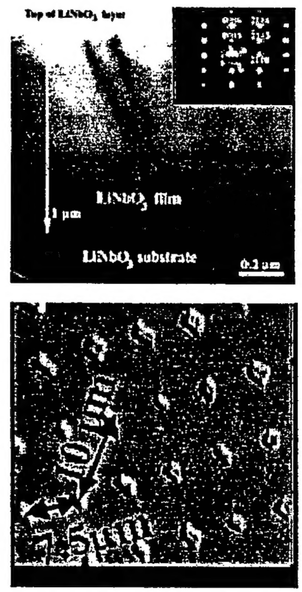

Fig. 3. (a) TEM of amorphous LiNbO3 after annealing; (b) patterned, etched, and annealed LiNbO3 film.

In parallel with this homoepitaxial technique, we have been exploring the growth of discontinuous patterned films on substrates with smaller refractive indices. We have found, for example, that under the proper conditions $LiNbO_3$ will undergo island growth on c-cut sapphire. X-ray diffraction shows the $LiNbO_3$ to be crystalline within the body of the islands. (It is likely that the island growth serves to relieve the lattice mismatch strain in the film.) With a properly patterned sapphire substrate, it may be possible to grow $LiNbO_3$ nonlinear photonic crystals via thin film epitaxy. The lower-index sapphire will additionally serve as optical cladding, confining the light to the $LiNbO_3$. What is perhaps more exciting are the recent Maker fringe measurements made by one of our collaborators, Prof. Theresa Maldonado of the University of Texas at Arlington, showing that the ferroelectric domains of these films are oriented, giving rise to a large second harmonic signal (Fig. 4). This implies that $LiNbO_3/Al_2O_3$ photonic crystals will also exhibit the desired second second order nonlinearity, without having to orient the ferroelectric domains after growth.

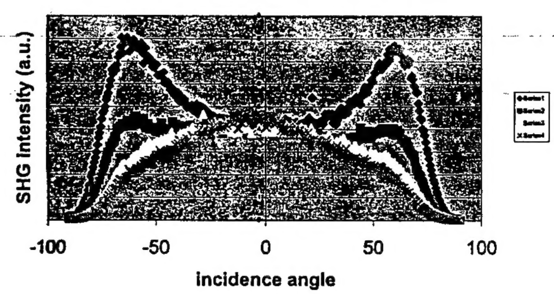

Figure 4. Maker fringe analysis of $LiNbO_3$ islands grown on c-cut sapphire.

References:

1. Aref Chowdhury, Chad Staus, Brian F. Boland, Thomas F. Kuech* and Leon McCaughan, " Experimental Demonstration of 1535-1555 nm Simultaneous Optical Wavelength Interchange with a Nonlinear Photonic Crystal," Opt. Lett., 26, 1353 (2001)
2. A. Chowdhury, C. Staus, B. Boland, T. F. Kuech, L. McCaughan, "Experimental Demonstration of Simultaneous Optical Wavelength Interchange with a Nonlinear

Photonic Crystal," presented at the Nonlinear Guide Wave Optics Topical Meeting, Clearwater, FL, Paper TuC2.

3. A. Chowdhury, C. Staus, B. Boland, T. F. Kuech, L. McCaughan, "Optical Wavelength Interchange Based on Nonlinear Photonic Crystals," presented at the March '01 Optical Fiber Conference, Anaheim CA.

4.V. Joshkin, K. Dovidenko, Oktyabrsky, D. Saulys, T. F. Kuech, L. McCaughan, "Two stage growth of patterned epitaxial lithium niobate for photonics applications, presented Sept 01 at the 13th Int'l Vacuum Society Symposium, San Francisco, paper PH-ThM9.

5. New Methods for Fabricating Patterned Lithium Niobate for Photonic Applications V. Joshkin, K. Dovidenko, S. Oktyabrsky, D. Saulys, T. Kuech, and L.McCaughan submitted to Applied Physics Lett.

Patent Disclosures

1.New Integrated Optics Devices enabled by the ability to fabricate 2D and 3D structures in $LiNbO_3$ via amorphous film growth and laser ablation, L.McCaughan, C. Staus, disclosure filed 1/02.

2.Geometries produced in bulk $LiNbO_3$ by laser ablation using a frequency tripled Nd:YAG," L. McCaughan, C. Staus, disclosure filed 1/02.